AN ECONOMIC ANALYSIS OF AUTOMATING A SMALL FLUID MILK PLANT

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AN ECONOMIC ANALYSIS OF AUTOMATING A SMALL FLUID MILK PLANT

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SUMMARY

Engineers of the Transportation and Facilities Research Division field office, Columbia, Mo., in cooperation with food scientists of the Department of Food Science and Nutrition, Missouri Agricultural Experiment Station, University of Missouri, Columbia, designed and installed an automated system in the fluid milk processing line in the University of Missouri dairy plant. The additions to the processing line consisted of the installation of:

1. Air actuated valves and CIP (cleaned-in-place) fixtures.
2. A two-speed sanitary centrifugal pump.
3. A liquid level controller and a spray tube for the vacuum chamber.
4. A control system that permits the homogenizer to be CIP cleaned with the processing line.

The processing system was designed to incorporate safety features that equal or exceed those required by the U.S. Public Health Service and by State and local regulations.

All of the savings resulting from the automated system were in reduced labor costs. Equipment costs were higher. The labor cost for operating the plant was $28,184 per year before automation and $21,096 after automation—a saving of $7,088. The total annual ownership and operating cost of the automated equipment was $4,905, resulting in a net saving of $2,183 as a result of automation. Approximately 65 percent of the saving was for homogenized milk. Slight increases in cost as a result of automation were indicated for coffee cream and whipping cream. The reason for this increase was that the very small volume of these products was not adequate for them to absorb their share of the increased equipment costs.

The automated system of processing was not as economical when product volume was small as when it was large. On days when the volume of product processed was small, the time used for cleaning tended to increase and fill the time not used for processing.

INTRODUCTION

Will automation of a small fluid milk processing plant reduce production costs enough to pay for the automated equipment installed? This question is the one managers and owners of small dairy plants are asking themselves. If they are to continue operating, they must compete with larger automated plants. The objective of automating a fluid milk processing plant is to reduce the labor requirements for performing the processing operations without sacrificing either the healthfulness or the quality of the finished product.

Owners and managers should profit from results of the research reported herein in making decisions about installation of automated equipment. However, an automated system must always be designed specifically for the individual dairy plant.

This study was concerned with the economic analysis of automating the processing line in a small-capacity fluid milk plant. The automated equipment installed consisted of control equipment,

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piping, valving, a two-speed sanitary centrifugal pump, and a CIP cleaning system. The incorporated design minimized the equipment used, permitted complete CIP cleaning, and met Federal, State, and local regulations regarding installation and operation. The original processing equipment in the plant was used and was integrated with the automated fluid milk processing system. Detailed descriptions of the processing line and the CIP cleaning system installed in the plant have been covered previously in three publications by Anderson and others.[2]

Engineers of the Transportation and Facilities Research Division field office at Columbia, Missouri, in cooperation with food scientists of the Food Science and Nutrition Department, Missouri Agricultural Experiment Station, University of Missouri, Columbia, conducted an economic analysis of the automated system. This system was installed in the dairy plant at the University of Missouri at Columbia and has been operating on a regular processing schedule. The system has been in service for almost 5 years without a significant malfunction of any kind. A brief description of plant operations is presented as an aid in understanding the economic analysis.

DESCRIPTION OF PLANT OPERATIONS

Raw milk is received into either of two raw milk storage tanks (fig. 1): the receiving of raw milk was not automated. From either of these tanks the milk flows by gravity to the positive pump, which forces the milk through the separator-clarifier.

When milk is being batch standarized (excess fat removed), the skim milk is returned to the storage tank from which the raw whole milk is pumped, and the cream is collected in cans.

During processing, milk is pumped through the separator-clarifier to the 110-gallon batching tank from which it is moved by a centrifugal booster pump to the constant level tank.

Milk is drawn by vacuum from the constant level tank through the regenerative section of the pasteurizer, through a throttle valve, and into the vacuum chamber. The level of milk in the vacuum chamber is monitored by a liquid level controller that regulates the throttle valve.

Milk is removed from the vacuum chamber by the two-speed centrifugal pump (low speed) and circulated to the homogenizer. The homogenizer, which also serves as the timing pump, circulates the milk through the remaining parts of the processing system.

The milk flows through the heating section of the pasteurizer, to the holding tube, and to the flow-diversion valve.

With the flow-diversion valve in the divert-flow position, the milk first returns to the constant level tank from which it re-enters the processing line. When the pasteurization temperature has been reached, the flow-diversion valve moves to the forward-flow position, allowing the pasteurized milk to flow through the regenerative and cooling sections of the pasteurizer to the flow-control valve.

The flow-control valve directs the flow of milk either to the pasteurized milk storage tanks and the packaging equipment or back to the constant level tank (if the milk is to be recirculated through the system, as when starting up or when changing product).

Valves in front of the two pasteurized milk storage tanks direct the flow of milk that passes through the flow-control valve to either of the pasteurized storage tanks or to the packaging equipment.

The design of the system permits the entire processing line to be CIP cleaned as a unit; cleaning solutions follow the same path as the milk. Either of the two pasteurized milk storage tanks can be CIP cleaned along with the processing line. Each of the four milk storage tanks—two raw milk storage tanks and two pasteurized milk storage tanks—can be CIP cleaned separately without interfering with the processing cycle.

The cleaning solutions—rinse, acid, and alkali—are made up in the CIP tank assembly. Cleaning, as used in this report, includes the sanitizing cycle. The CIP pump circulates the cleaning solution to the equipment being cleaned. The CIP return pump forces the cleaning solution back to the CIP tank assembly and directs it to the

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[2]Anderson, M.E., Webb, T.F., Marshall, R.T., and Shelley, D.S. Adapting the flow-diversion valve and homogenizer to permit automated cleaning-in-place of milk processing lines. U.S. Dept. Agr., Agr. Res. Serv. ARS 52-31, 18 pp., illus., January 1969.

Anderson, M.E., Marshall, R.T., and Webb, T.F. Automating a fluid milk processing line—equipment and procedures. U.S. Dept. Agr., Agr. Res. Serv. ARS 52-45, 28 pp., illus., February 1970.

Anderson, M.E., Marshall, R.T., and Webb, T.F. Equipment and operating procedures for an automated cleaning system in a milk processing plant. U.S. Dept. Agr., Agr. Res. Serv. ARS 52-49, 48 pp., illus., March 1971.

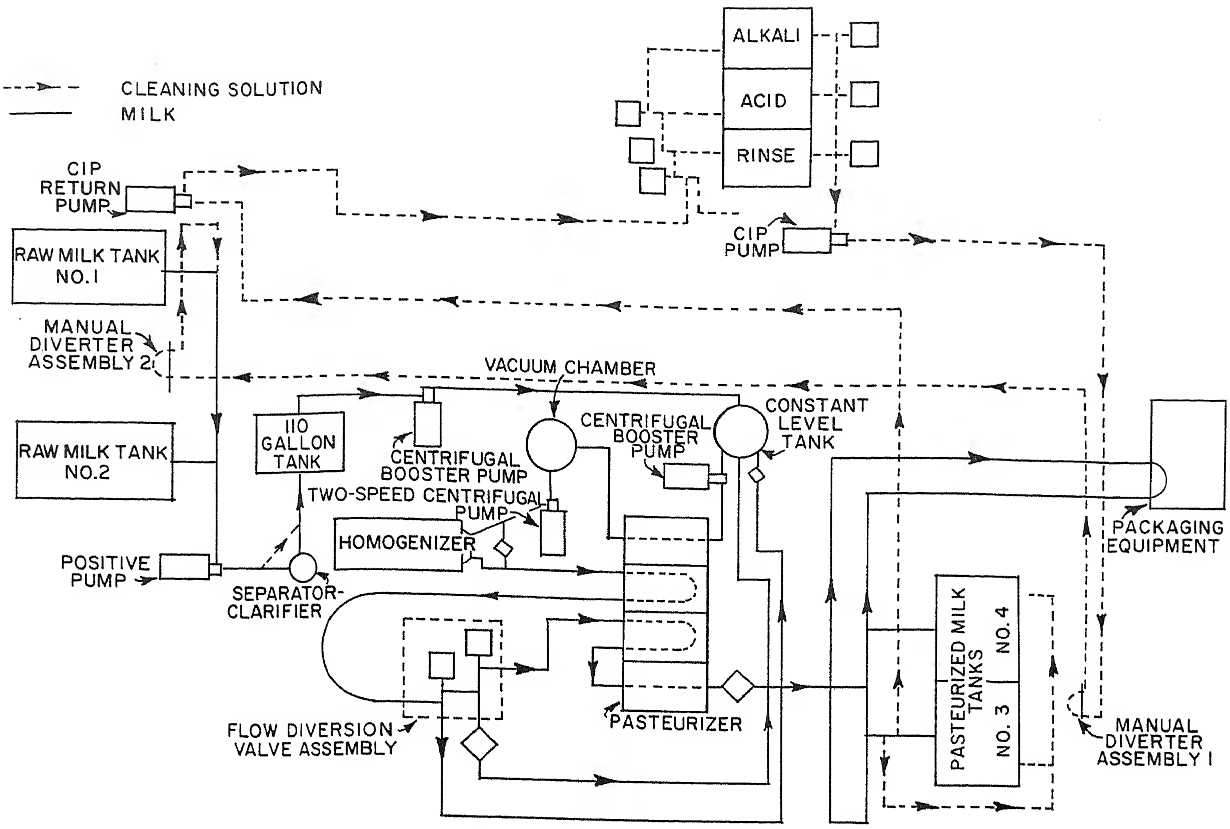

Figure 1.–Diagram showing flow of milk and cleaning solution through the processing line.

proper tank or to the drain.

Because the cleaning solution follows the same path through the processing line as the milk, the following simple manual operations prepare the processing line for cleaning:

1. Remove a flow-restricting orifice from the line connecting the flow-diversion valve to the constant level tank.
2. Disconnect the separator-clarifier from the processing line.
3. Move manual diverter assembly 1 and assembly 2 (fig. 1) to the proper positions.
4. Connect the pasteurized milk tank to be cleaned with the processing line.
5 Move the flow-diversion valve control switch from the processing line to the cleaning cycle.
6. Set the selector switches for the equipment to be cleaned and the cleaning cycle to the proper positions and press the starter button. (The cleaning cycle for the processing line runs for 1 hour.)

PROCEDURE FOR DETERMINING EFFECTS OF AUTOMATION ON COSTS

The effects of automation on plant operation costs were analyzed by determining labor and equipment costs before and after automation.

The labor cost was determined by recording the amount of labor used in processing each product each day and applying the appropriate pay rate. Each day a time card (fig. 2) was filled out by each employee. For each job assignment, the time that

Name	Date
Job	Time Started

Figure 2.–Sample card filled out by each employee each work day, showing time each new job was started.

processing started and the name of the product were recorded. This system of recording time required the full workday to be allocated to individual jobs. Cleaning was handled as a plant-wide operation and was not assigned to individual products.

Records of labor used were kept for 160 days before automation and 49 days after automation.

The fixed and variable costs of the automated control equipment for the processing line were determined. This cost analysis included only the items that were installed to permit the plant to be automated. The total cost of the automated equipment installed was $25,750.50. The following tabulation shows the quantity and cost of the various pieces of equipment:

Equipment

Quantity	Equipment	*Cost*
1	Main control panel	$ 600.00
1	Auxiliary control panel	100.00
1	Liquid-level control unit (installed)	1,800.00
10	Three-position switches with indicator lights	200.00
3	Selector switches (multideck)	120.00
9	Relays, industrial type	180.00
4	Relays, plug-in type	28.00
16	Sanitary valve units	4,800.00
--	Miscellaneous pipes and fittings	400.00
--	Miscellaneous electrical components (wires, terminal boards, etc.) and labor for initial wiring	500.00
1	CIP flow-diversion valve (2-inch ID)	1,397.25
1	Sight glass	127.65
1	Liquid level control with spray tube and throttle	950.40
1	Bypass valve	310.50
1	CIP booster pump (includes starter)	414.00
1	Two-speed centrifugal pump (includes starters)	802.70
1	Auxiliary control panel	230.00
1	Solution supply tank (three compartment)	1,600.00
3	Shutoff valves	675.00
3	Direct valves	780.00
1	CIP pump unit	550.00
1	CIP return pump	400.00
1	Alkali metering device	150.00
1	Acid metering device	225.00
1	Chlorine metering device	200.00
3	Temperature controllers	540.00
--	Electrical controls for panel (relays, cam timers, etc.)	1,000.00
3	Water makeup units	270.00
2	Valve pulser units	100.00
--	Piping and fittings for CIP lines	300.00
	Total cost of equipment	$19,750.50
	Estimated cost of installation	6,000.00
	Total cost of system installed	$25,750.50

Fixed Cost

Depreciation (based on average life of 12 years)[3]:	
0.0833 x $25,750.50	$2,145.02
Taxes and insurance (based on 4 percent of initial investment):	
0.04 x $25,750.50	1,030.02
Interest (based on 6 percent* of average investment):	
0.0325 x $25,750.50	836.89
Total fixed cost per year	$4,011.93

$$* \; E = \frac{I\,(N+1)}{2N} = \frac{.06\;(12+1)}{2\;(12)} = 0.0325$$

N = Average life
I = Interest rate

Variable Cost

CIP pump (7½ hp. @ 0.8 efficiency x 746 watts/hp. x $0.02/kw.-hr.)	$ 0.14/hr.
CIP return pump (3 hp. @ 0.8 efficiency x 746 watts/hp. x $0.02/kw.-hr.)	.06/hr.
Total electrical cost	$ 0.20/hr.
Cost of electricity for the two CIP pumps ($0.20/hr. x 2 hrs./day x 5 days/week x 52 weeks/year)	104.00
Control panel (500 watts/hr. x $0.02/kw.-hr. x 6.5 hrs./day x 5 days/week x 52 weeks/year)	16.90
Maintenance (estimated at 3 percent of initial cost per year—0.03 x $25,750.50)	772.52
Total variable cost	$ 893.42

Total Cost

Total fixed cost	$4,011.93
Total variable cost	893.42
Total annual cost	$4,905.35

[3] Depreciation based on "Depreciation Guidelines and Rules," Internal Revenue Service Publication 456, 92 pp. 1964.

BENEFITS OF AUTOMATION

A summary of labor used is shown in table 1. The plant labor used was reduced as a result of automation by an average of 401.5 man-minutes per day. Processing time was reduced by 75.2 man-minutes and cleaning time by 326.3. The labor usage ratio (pounds processed divided by man-minutes) for processing increased by 1.97 pounds per man-minute and that for cleaning increased by 24.20. The total labor usage ratio increased by 2.80 pounds per man-minute.

After automation, the volume of product processed increased because of increased demand,

Table 1.–Labor utilization for the University of Missouri milk plant before and after automation

Type of plant	Amount of product processed	Labor used			Labor usage ratio		
		Processing	Cleaning	Total	Processing	Cleaning	Total
	Pounds	*Man-minutes*	*Man-minutes*	*Man-minutes*	*Pounds/ man-minute*	*Pounds/ man-minute*	*Pounds/ man-minute*
Ionautomated ..	13,893	1,345.5	695.5	2,041.0	10.53	21.12	6.88
ıutomated	15,746	1,270.3	369.2	1,639.5	12.50	45.32	9.68
Change	1,853	75.2	326.3	401.5	1.97	24.20	2.80

ɔut the amount of labor used decreased (table 1). For this reason, the record of labor used before and ıfter automation was related to the volume of prodıct processed by the use of regression analysis.[4] A inear relationship was determined to exist for processing time, cleaning time, and total time with volume of product processed (fig. 3.).

The cleaning curves, which were not significantly different at the 95-percent level, have a negative slope. The negative slope was caused by an inverse relationship between volume of product processed and man-minutes used for cleaning. In explanation: On days when the quantity of product processed was

[4]Snedecor, G.W., and Cochran, W.G. Statistical methods. Ed. 6, 593 pp. Iowa State College Press, Ames, Iowa, 1967.

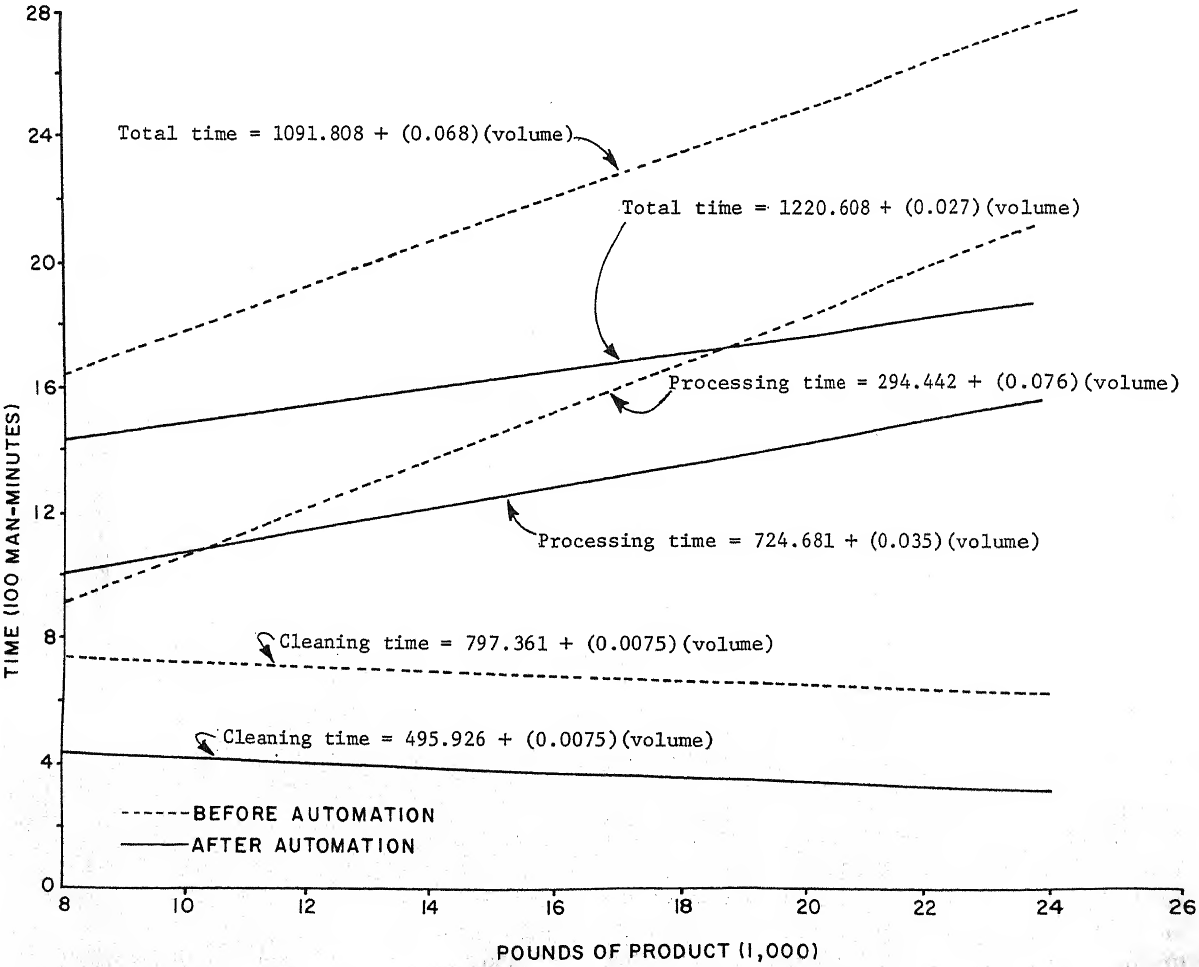

Figure 3.–Relationship between man-minutes of time required and volume of product processed before and after automation.

small, the time used for cleaning tended to increase and fill the time not used for processing. However, the time saved for cleaning, 5.02 man-hours per day, was independent of the volume of product processed.

The slope of the curves for processing time before and after automation was significantly different ($P<0.05$). After automation, the labor required continued to increase as increments of volume were added, but at a decreasing rate. It is evident, therefore, that the "economy of scale" principle applies. The automated system of processing was not as economical when product volume was small as when it was large. The data indicated that during periods of small volume employees tended to stretch their work in order to complete a full day. When compared with results from the nonautomated operation, 1.72 more man-hours per day were required for the automated operation when only 8,000 pounds were processed; 0.35 more when 10,000 pounds were processed. However, as volume increased to that normally processed, about 16,000 pounds, the savings in processing time was 3.76 man-hours per day.

Considering the entire automated system, both processing and cleaning, the savings in man-hours increased as volume of product increased—from 3.41 man-hours per day for 8,000 pounds of product to 13.15 for 22,000 pounds.

The total volume of product that must be processed to pay for automation decreased as plant wage rates increased. The return on investment that accrued as a result of automation was calculated for processing volumes of from 8,000 to 22,000 pounds per day for four plant wage rates (fig. 4). Data for costs of equipment and labor were used for calculating the return. The horizontal line indicates that to break even the total volume of product processed and the wage rates would be as follows:

Products processed per day	Wages paid per hour
Pounds	
15,800	$2.00
12,150	3.00
9,930	4.00
8,550	5.00

Data were developed to show how automation affects the labor cost of the individual products processed. It is important to know which products contributed most to savings in labor, as this is the basis for justifying plant automation.

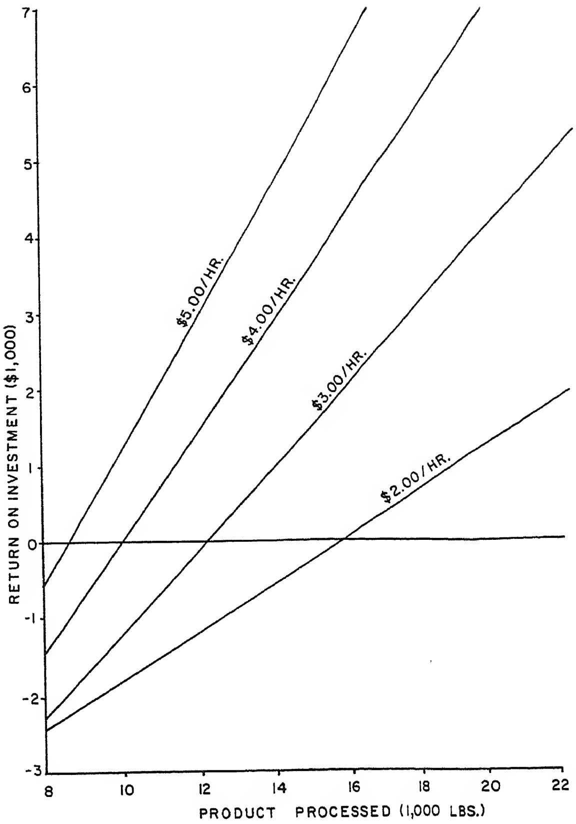

Figure 4.–Return on investment versus volume of product processed for four plant wage rates.

Although product demand increased after automation (an average of 15,746 pounds of raw milk per day was processed after automation as compared with 13,893 before), proportion of each product processed did not differ essentially. The percentages of the various products processed were:

Product	Volume processed
	Percent
Homogenized milk	73.0
Skim milk	14.5
Chocolate milk	8.0
Cereal milk (half and half)	2.3
Minor products (buttermilk, coffee cream, whipping cream)	2.2

The total volume of milk packaged in various sizes of containers per day did change after automation. Volumes of the various products processed and the sizes of containers into which the products were packaged are shown in table 2. After automation the total volume of homogenized milk packaged in half-pint and quart cartons decreased, whereas the total volume of homogenized milk

Table 2.–Products processed, daily volumes, and number of containers used to determine economies of automation in a small dairy plant

Product processed	Daily volume	Containers used				
		Half-pint carton	Quart carton	3-gallon box	6-gallon box	10-gallon can
	Pounds	*Number*	*Number*	*Number*	*Number*	*Number*
Homogenized milk:						
Nonautomated ..	10,222	1,981.3	242.9	9.0	148.3	11.1
Automated	11,550	1,892.7	191.3	26.7	166.6	9.3
Skim milk:						
Nonautomated ..	1,970	600.2	0	0	31.8	0
Automated	2,400	310.4	0	0	44.2	0
Chocolate milk:						
Nonautomated ..	1,219	870.4	22.5	0	15.9	4.6
Automated	1,360	832.1	20.7	0	20.4	0
Cereal milk:						
Nonautomated ..	365	224.0	229.3	0	0	0
Automated	309	0	194.2	0	0	0
Buttermilk:						
Nonautomated ..	239	258.9	30.7	0	0	0
Automated	249	245.3	34.1	0	0	0
Coffee cream:						
Nonautomated ..	34	7.1	24.0	0	0	0
Automated	15	7.8	7.8	0	0	0
Whipping cream:						
Nonautomated ..	54	10.5	23.8	0	0	0
Automated	84	17.4	37.6	0	0	0

packaged in 3- and 6- gallon plastic bags in boxes increased. The total volume of homogenized milk packaged in 10-gallon cans decreased slightly. The total volume of skim milk packaged in half-pint cartons decreased by about one-half, about 300 cartons per day. The total volume of skim milk packaged in 6-gallon boxes increased by about 74 gallons per day. The total volume of chocolate milk packaged in half-pint and quart cartons remained relatively constant for the test period, but the total volume of chocolate milk packaged in 6-gallon boxes increased by about 24 gallons per day. No cereal milk was packaged in half-pint cartons after automation, and the total volume placed in quart cartons decreased by about 35 quarts per day. The total volume of each of the minor products packaged (buttermilk, coffee cream, and whipping cream) did not change significantly after automation.

Table 3 shows the average time requirements for processing, packaging, and cleaning the seven products before and after automation.

The reduction in processing time after automation for homogenized milk is approximately 100 man-minutes, in spite of the increase in the volume of homogenized milk processed. Table 3 shows that packaging time increased after automation because, even though the product was packaged at a fixed rate, the volume increased. The reduction in cleaning time allotted to homogenized milk was 243 man-minutes. Cleaning time allocated to individual products was based on the percentage of the total pounds of raw product processed.

The processing time for skim milk remained essentially the same after automation, although the volume of product processed increased by about 430 pounds. The packaging time for skim milk also remained essentially the same because of a decrease in half-pint cartons and an increase in 6-gallon boxes. The cleaning time allocated to skim milk was 98 man-minutes before automation and 60 man-minutes after automation, a decrease of approximately one-third.

The processing and packaging time for chocolate milk remained essentially the same after automation; however, the cleaning time decreased by about one-half.

The processing and packaging time for cereal milk did not change significantly, but the cleaning time decreased slightly.

The savings due to automation and allocated to minor products were not significant.

Table 4 shows labor costs in cents per container for processing and packaging the products in

Table 3.—Average daily time requirements for processing, packaging, and cleaning in a small dairy plant, before and after automation

Product processed	Processing time		Packaging time		Cleaning time	
	Nonautomated	Automated	Nonautomated	Automated	Nonautomated	Automated
	Man-minutes	*Man-minutes*	*Man-minutes*	*Man-minutes*	*Man-minutes*	*Man-minutes*
Homogenized milk	426.3	320.7	469.9	529.6	513.7	270.2
Skim milk	91.9	85.5	121.7	122.5	98.0	60.8
Chocolate milk	72.5	77.2	86.7	95.6	63.5	31.2
Cereal milk	19.6	18.7	37.3	31.6	17.0	13.1
Buttermilk	5.8	1.2	39.1	43.6	15.9	5.7
Coffee cream	1.4	1.2	14.3	18.1	1.7	.3
Whipping cream	1.2	.94	16.3	19.0	2.7	2.2

various container sizes before and after automation. Prorated labor costs are given for the various products in each container size, even though no product may have been packaged in that specific container.

Homogenized milk, the major product processed, contributed most to the savings from automation. Labor costs for homogenized milk were reduced by 0.108 cents per half-pint, 0.429 cents per quart, 5.47 cents per 3-gallon box, 10.943 cents per 6-gallon box, and 18.237 cents per 10-gallon can.

Table 5 shows the average daily labor costs for products processed and the numbers of containers in which the product was packaged. These figures indicate that automation reduces labor costs when a large volume of products is processed; however, automation may increase the labor costs when a small volume is processed.

For the total products processed, the daily net savings was $27.26 (table 5). Of this amount, $17.76 was saved in processing homogenized milk. At this rate, 161 days of operation would be necessary to pay the yearly costs of the automated equipment. On an annual basis, the savings due to automation is $7,088. The total annual cost of owning and operating the automated system is $4,905. The annual net savings for this small fluid milk plant is $2,183.

Table 4.—Labor cost for processing and packaging, by product and container size, before and after automation

Product processed	Labor cost per container				
	Half-pint carton	Quart carton	3-gallon box	6-gallon box	10-gallon can
	Cents	*Cents*	*Cents*	*Cents*	*Cents*
Homogenized milk:					
Nonautomated	.571	1.295	15.857	31.215	46.691
Automated	.463	.866	10.386	20.272	28.454
Skim milk:					
Nonautomated	.771	1.556	16.886	33.272	50.121
Automated	.672	1.148	11.626	22.752	32.586
Chocolate milk:					
Nonautomated	.651	1.497	17.970	35.439	53.731
Automated	.578	1.246	14.900	29.299	43.497
Cereal milk:					
Nonautomated	1.138	1.894	16.415	32.330	48.550
Automated	1.088	1.866	16.781	33.062	49.771
Buttermilk:					
Nonautomated	.926	1.627	15.460	30.421	45.368
Automated	.777	.934	6.054	11.608	14.013
Coffee cream:					
Nonautomated	2.568	3.078	12.221	23.943	34.572
Automated	6.119	6.332	7.143	13.786	17.643
Whipping cream:					
Nonautomated	2.662	3.141	11.673	22.854	32.743
Automated	2.688	2.853	6.311	12.126	14.871

Table 5.—Average daily number of containers used and labor cost, by product processed, before and after automation[1]

Product processed	Half-pint		Quart		3-gallon box		6-gallon box		10-gallon can		Total labor cost	Net savings from automation
	Containers	Labor cost	Containers	Labor cost	Containers	Labor cost	Containers	Labor cost	Containers	Labor cost		
	Number	*Dollars*	*Number*	*Dollars*	*Number*	*Dollars*	*Number*	*Dollars*	*Number*	*Dollars*	*Dollars*	*Dollars*
Homogenized milk:												
Nonautomated ..	1,981.3	11.31	242.9	3.15	9.0	1.43	148.3	46.29	11.1	5.18	67.36	---
Automated	1,892.7	8.76	191.3	1.65	26.7	2.77	166.6	33.77	9.3	2.65	49.60	17.76
Skim milk:												
Nonautomated ..	600.2	4.62	0	0	0	0	31.8	10.58	0	0	15.20	---
Automated	310.4	2.09	0	0	0	0	44.2	10.06	0	0	12.15	3.05
Chocolate milk:												
Nonautomated ..	870.4	5.66	22.5	.34	0	0	15.9	5.63	4.6	2.47	14.10	---
Automated	832.1	4.80	20.7	.26	0	0	20.4	5.98	0	0	11.04	3.06
Cereal milk:												
Nonautomated ..	224.0	2.55	229.3	4.35	0	0	0	0	0	0	6.90	---
Automated	0	0	194.2	3.62	0	0	0	0	0	0	3.62	3.28
Buttermilk:												
Nonautomated ..	258.9	2.40	30.7	.49	0	0	0	0	0	0	2.89	---
Automated	245.3	1.90	34.1	.32	0	0	0	0	0	0	2.22	0.67
Coffee cream:												
Nonautomated ..	7.1	.18	24.0	.74	0	0	0	0	0	0	.92	---
Automated	7.8	.48	7.8	.49	0	0	0	0	0	0	.97	-0.05
Whipping cream:												
Nonautomated ..	10.5	.28	23.8	.75	0	0	0	0	0	0	1.03	---
Automated	17.4	.47	37.6	1.07	0	0	0	0	0	0	1.54	-0.51
Total nonautomated costs											108.40	---
Total automated costs											81.14	---
Savings resulting daily from automation											---	27.26

[1] Costs charged to individual products only for days that product was processed.